In Situ Yogurt Production for Probiotic and Nutrition Delivery

Completed Technology Project (2016 - 2017)

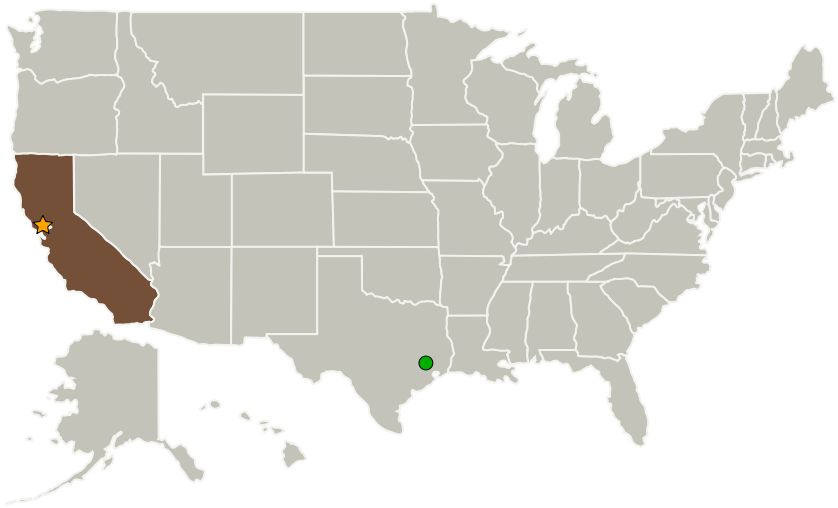
Project Introduction

The technical approach to meeting the objectives above includes the development of a packet system that stores dried milk solids and a preserved form of the multiple yogurt culture microbes. When needed, the packet would be hydrated using a typical food hydration system already in use in spacecraft. The hydrated packet would be incubated at an elevated temperature for a determined period and then either refrigerated for storage or consumed immediately.

Anticipated Benefits

Providing human nutrition and maintaining overall crew health and well-being poses major challenges, particularly in long duration missions. Certain nutrients degrade in stored foods and supplements with time, and will require generation in situ. Likewise, the crew's microbiome status is of major concern, as this is a strong determinant of overall health. Additionally, the psychological well-being of the crew is tightly coupled with the availability of familiar, good tasting and nutritious food. This project aims to address all three of these mission needs by providing the capability to locally generate fresh, nutritious food that also serves to maintain the crew's microbiome health. This approach can be employed in any mission scenario, including ISS and beyond LEO exploration

Primary U.S. Work Locations and Key Partners



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Organizations Performing Work	Role	Type	Location
Ames Research Center(ARC)	Lead Organization	NASA Center	Moffett Field, California
Johnson Space Center(JSC)	Supporting Organization	NASA Center	Houston, Texas

Primary U.S. Work Locations
California

Project Transitions

October 2016: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Ames Research Center (ARC)

Responsible Program:

Center Innovation Fund: ARC CIF

Project Management

Program Director:

Michael R Lapointe

Program Manager:

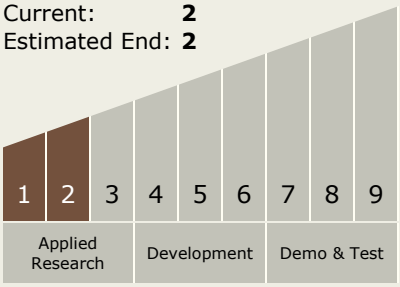
Harry Partridge

Principal Investigator:

John A Hogan

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **2**



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July 2017: Closed out

Closeout Summary: This project focused on two main research areas: 1) The development of a space-ready yogurt starter culture, and an associated engineering demonstration, and 2) The development of a preliminary disposable packet system and concept of operations that is capable of storing the media and microbes and also allows yogurt production. The results attained in these two areas are discussed below.Space-ready yogurt culture development - The yogurt starting culture must be able to withstand storage in space for extended periods, especially if used on multi-year missions such as Mars habitation scenarios. Genetic engineering of the starter culture can potentially allow expression of desiccation and or radiation tolerance genes to extend the shelf-life of the yogurt starter strain. In addition, engineering could also enable the production of targeted vitamins, nutraceuticals, useful enzymes, and medicines. As a demonstration of this potential, we engineered green fluorescence protein (GFP) into one of the yogurt starter strains, *Streptococcus thermophilus* to facilitate detection. The engineered strain was used to make yogurt containing GFP which was analyzed by fluorescence microscopy. The engineered strain retained the GFP gene in a plasmid vector during the yogurt incubation period even in the absence of the selective antibiotic, chloramphenicol, which ensured that genetic engineering of the starter strain is compatible with production of antibiotic-free yogurt for safe consumption. This demonstration indicates that other, more complex, engineering efforts for stasis and targeted products may be warranted. The other approach involved using other relevant Generally Regarded As Safe (GRAS) microbes for yogurt production. *Bacillus coagulans* and *B. subtilis* (Fig. 2) were chosen because they are probiotic, form very stable spores which tolerate long-term storage and naturally produce vitamin K which is found deficient in the current astronauts' diet. We made yogurt by using Bacillus strains alone or with conventional yogurt starter strains. Yogurt made from Bacillus species alone was not as acidic as that with yogurt starters and had cheesy flavor.Prototype flight yogurt production system - We designed and successfully tested a packet system using a food-compatible plastic bag and associated fittings to store the dry milk powder and starter culture separately. This allowed initial scalding of the milk with hot water to inactivate potential contaminating microbes. The separation was removed to allow mixing of the milk and culture after the milk had cooled down. The temperature was monitored by a contact liquid crystal thermometer on the packet surface. In addition, we designed a powered, dedicated yogurt incubation system to maintain the mixture at 44^{o}C for 8 hrs. and cool it down to 4^{o}C until serving. The system utilizes a switchable thermoelectric heating/cooling process to maintain reliability and simplicity. A variant of this system could be utilized for actual operations. This project started at a Technology Readiness Level (TRL) of 1. The work completed during this project brought it to approximately a TRL of 3 as we conducted laboratory research and analyses that validated the overall concept. Future work would need to focus on increasing organism longevity, validating the concept in spaceflight, and the development of food safety monitoring and control systems.

Technology Areas

Primary:

- TX07 Exploration Destination Systems
  - TX07.2 Mission Infrastructure, Sustainability, and Supportability
    - TX07.2.1 Logistics Management

Target Destinations

The Moon, Mars, Earth

Supported Mission Type

Push